Multi-messenger searches of neutrino sources driven by gamma-ray observations

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Introduction

After more than 100 years since their discovery, cosmic rays (CRs) are still one of the most intriguing open questions in astrophysics. Intrinsic difficulties are unavoidable when trying to identify the sites of production and acceleration of these charged particles due to the magnetic deflections they undergo. However, in the era of multi-messenger astrophysics hints of a cosmic accelerator might come from the detection of high-energy γ rays and/or neutrinos that are expected to be produced by the interactions of CRs with the ambient matter and radiation in the vicinity of a potential source. This poster presents the most important analyses regarding searches for neutrino point-like sources performed by the university of Geneva and based on insights from γ-ray observations.

TXS 0506+056: the dawn of multi-messenger neutrinos

On 22 September 2017 a high-energy neutrino event detected by IceCube (most probable energy 290 TeV at 90% confidence level) from a region of the sky compatible with the coordinates of the blazar TXS 0506+056 triggered a follow-up of γ-ray experiments. In the subsequent days, many of these experiments observed an increased activity of γ rays from a direction compatible with the region of the neutrino alert [1]. In a subsequent time-dependent analysis at the coordinates of TXS 0506+056, the IceCube group in Geneva observed a notable flare in December 2014, prior to the event alert, with a significance of 3.5σ [2]. TXS 0506+056 became the first evident multi-messenger source of neutrinos and γ rays.

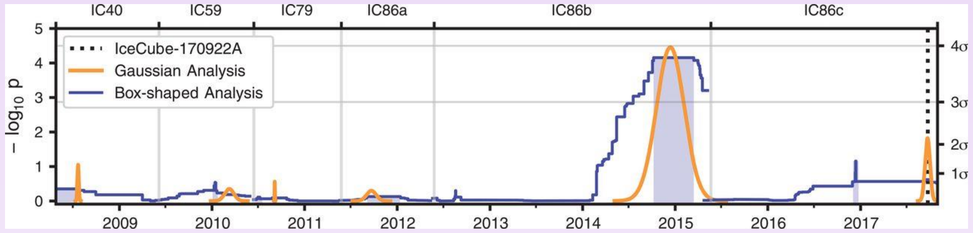

Fig. 1: Neutrino best-fit flares at the location of TXS 0506+056 prior to the IceCube-170922A alert [2]

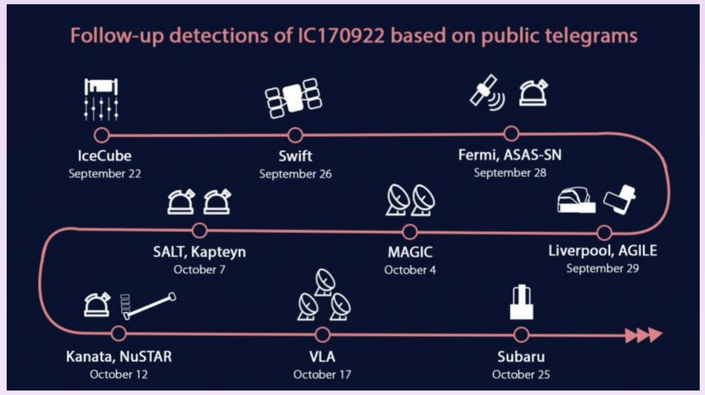

Fig. 2: Gamma-ray follow up of the neutrino alert

NGC 1068: a neutrino discovery based on gamma-ray observations

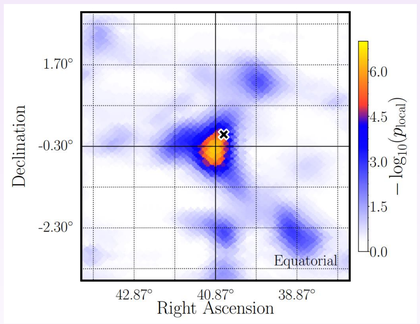

Fig. 3: p-value map of a time-integrated all-sky neutrino search. The black cross marks the coordinates of NGC 1068 [3]

Recently the IceCube group in Geneva observed further evidences of neutrino sources [3]. A time-integrated analysis of a catalog of 110 selected γ-ray emitters (mainly based on the Fermi-LAT 4FGL catalog) observed a cumulative excess at 3.3σ-level in the neutrino flux emitted across 10 years by four of these potential sources in the northern sky (declination $\delta > -5°$): NGC 1068, TXS 0506+056, PKS 1424+240 and GB6 J1542+6129. The most significant individual source of the catalog, NGC 1068, also very close the most significant northern spot in a time-integrated all-sky search, was observed with a p-value of 1.8×10^{-5}, that became 2.0×10^{-3} (2.9σ) after trial corrections due to the look-elsewhere effect

A multi-flare time-dependent follow-up of the catalog

Very recently, the IceCube group in Geneva performed a time-dependent follow-up on the same catalog with a multi-flare algorithm. The neutrino excess in the northern sky was confirmed at a significance of 3.0σ and is due mainly to M87, TXS 0506+056, NGC 1068, GB6 J1542+6129. M87, a galaxy whose core is a known emitter of ultra-relativistic ejecta, is the most significant source of the catalog, observed with a p-value of 4.3×10^{-2} (1.7σ) after trial corrections. TXS 0506+056 is a multiple flare source, with two notable flares reconstructed in December 2014 (see [2]) and September 2017 (related to the alert event, see [1]).

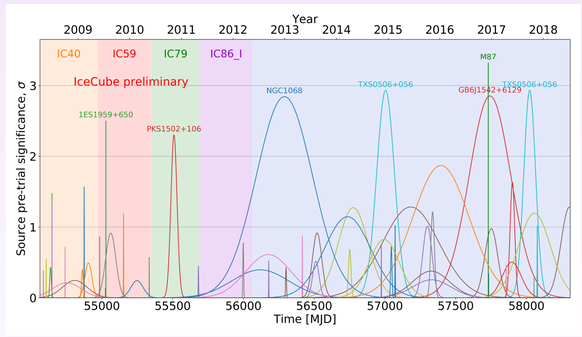

Fig. 4: Multi-flare neutrino best-fit flares of potential sources of a catalog selected on the basis of gamma-ray observations

Neutrino outlook with CTA

CTA has a dedicated multi-messenger program to investigate neutrino transients, and in synergy with current and future neutrino observatories (such as the next generation IceCube-Gen2) it might unveil new potential neutrino sources and help to reveal the origin of ultra-high-energy cosmic rays. Additionally, with a sensitivity that is about 10 times better than any existing gamma-ray instrument, reaching energies up to 300 TeV, CTA might investigate the origin of the TeV-PeV bulk of cosmic neutrinos detected by IceCube, addressing the question of galactic pevatrons. This will potentially open the window to the study of different transient events, like tidal disruption events, in which a star is swallowed by a supermassive black hole, low-luminosity gamma-ray bursts or supernovae with strong interactions with circumstellar material. The program is tailored to address transient phenomena and respond to alerts issued by neutrino observatories, such as IceCube, in a modern version of the so-called Neutrino Triggered Target of Opportunity (NToO) program.

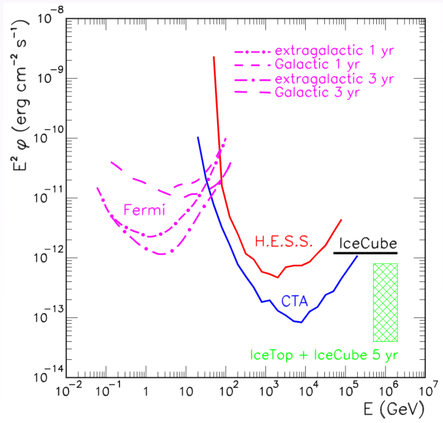

Fig. 5: CTA sensitivity (blue) and astrophysical neutrino flux measured by IceCube (black) [4]

References

[1] Aartsen et al., Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

[2] The IceCube collaboration, Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

[3] The IceCube collaboration, Time-Integrated Neutrino Source Searches with 10 Years of IceCube Data

[4] Anchordoqui et al., Cosmic Neutrino Pevatrons: A Brand New Pathway to Astronomy, Astrophysics, and Particle Physics